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Running Head: RELATIVE AGE EFFECTS IN THE WORLD'S BEST

New evidence of relative age effects in 'super-elite' sportsmen: a case for the survival **and** evolution of the fittest

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Key Words: physical maturation; cognitive development; skill acquisition; rocky road; resilience

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Abstract

Within sport, the relative age effect (RAE) describes an overrepresentation of players born early (Q1) in a selection year and is highly prevalent within youth sport pathways. This effect is generally shown to dissipate at senior-elite level, and a dearth of research has investigated the RAE at the 'super-elite' level. The present research assessed the presence of RAE in 'super-elite' performers. Study 1 investigated RAE in the world's best international Test cricketers (N = 262) over a 20 year period according to a robust and stringent 'super-elite' criteria. Results revealed an overall RAE (Q1) when all disciplines were combined. Upon closer examination, this effect was also observed for the batting and spin bowling disciplines, whereas no RAE was found for the pace bowling discipline. Study 2 investigated RAE in super-elite rugby union players (N = 691) over a 20 year period. Results revealed the RAE for backs (Q1) and a reversal of the traditional RAE (Q4) for forwards, and when all rugby union positions were combined. These findings provide new evidence of RAEs at the super-elite level and present both inter and intra sports differences. Potential explanations for these findings are explored, owing to the *survival* and *evolution* of the fittest concepts, and the implications for future research and applied practice are presented.

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Chronological age grouping of children in sport competitions may be disadvantageous to children and may hamper their future development (Crawford, Dearden & Meghir, 2007). That is, adopting chronological age grouping systems results in some children being almost a year younger than some other children in the same group. This process may eventually lead to the relative age effect (RAE) where relatively older children (Q1) are over-represented in comparison to the relatively younger (Q4) in a given age group. In sport, a plethora of research has demonstrated the breadth of the traditional RAE in youths across a number of sports, e.g. rugby union and cricket (Barney, 2015; Lewis, Morgan & Cooper, 2015).

Barnsley, Thompson and Barnsley (1985) provide the earliest evidence that RAE is associated with career success. They identified that players born earlier in the selection year were more likely to be labelled as talented and represent teams in the highest standard of competition, e.g. the National Hockey League (NHL), compared to their relatively younger counterparts. RAE in youth sport teams is often attributed to physical maturation differences (see Cobley, Baker, Wattie & McKenna, 2009), where chronologically older athletes are said to be more physically developed than the chronologically younger athletes, providing them with a competitive advantage. This competitive advantage is suggested to begin early in development, where players are initially selected (and subsequently remain attached) onto talent pathways based on prioritisation of early success, i.e. physical dominance (Bailey et al., 2010). This is indicative of the *survival of the fittest* concept, whereby those who demonstrate early physical maturity best fit the criteria of these selection processes (Christensen, Pedersen & Mortensen, 2008). Such a bias imposes a significant challenge for Q4 players wishing to progress along the sport player pathway, often resulting in 'de-selection', where the Q4 players who are least physically mature drop-out of the pathway. These Q4 players must then remerge as viable aquisitions via alternative means, for example

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by developing resilience as a result of de-selection experiences, reflective of the *evolution of the fittest* concept (Christensen et al., 2008; Hardy et al., 2017).

Recent research (McCarthy, Collins & Court, 2016) has examined RAE across key developmental milestones within professional rugby union and cricket academies. This study revealed a Q1 and Q2 overrepresentation at the initial selection point into academies. However, a reversal of this RAE (Q3 & Q4) was discovered when assessing the conversation rate of the academy players who 'graduate' to represent national level in their respective sports. Similar findings have been reported by Barney (2015) who conducted a study of RAE in cricket across the England & Wales cricket board's (ECB) entire player pathway and demonstrated that a Q1 and Q2 RAE existed from U12-U17 but a relatively higher proportion of Q3 and Q4 players were retained in the pathway as they progressed towards senior elite status (post U19).

Theoretical rationale for these RAE reversals at the youth towards senior elite level can be found in recent research. For example, MacNamara, Button & Collins (2010) identified several psychological characteristics for developing excellence in sport (PCDEs); the extent to which these characteristics are attained may depend on early experiences (Collins & MacNamara, 2012). The Q1 to Q4 RAE reversal has been attributed to the Q4 players' possessing a stronger psychological profile, developed by challenging developmental experiences, compared to their Q1 counterparts (McCarthy & Collins, 2014; McCarthy et al., 2016). Furthermore, emerging research has demonstrated that super-elite sportsmen encountered significant traumatic experiences during early development, before achieving international status (Hardy et al., 2017; Rees et al., 2016). Specifically, this has revealed that a foundational negative life event, coupled with positive sport-related support were the key differentiators between super-elite athletes (Olympic gold medallists) and elite athletes. Similarly, being a Q4 player is said to present psychological challenges, as well as physical

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challenges (Ford & Williams, 2011). Overcoming these challenges may be why a significant number of Q4 players are represented in elite sports programmes. This concept can be found in the 'Talent Needs Trauma' framework (Collins & MacNamara, 2012) which argues that the talent pathway should not be a comfortable place to be, rather, challenges are common in athletes who have developed psychological resilience and toughness, and reached the top. Development trajectories associated with such challenges are referred to as a 'rocky road' (McCarthy & Collins, 2010). For Q4 players, challenges include training and competing with those of a greater physical stature, or becoming de-selected from a sports programme. Providing these challenges are overcome with sufficient support, they can enhance the development of psychological resilience and toughness, preparing players for further challenges at the highest level (MacNamara, et al., 2010).

To the best of our knowledge, the only research which has examined RAEs in super-elite sportsmen (acclaimed for competing at the highest level of competition consistently) found evidence for differential RAEs across ice hockey positions, with a Q1 RAE identified for male goalies, but not the skater positions (Grondin & Trudeau, 1991). Addona and Yates (2010) later identified a strong RAE for Q1 Canadian players who had participated in the NHL from 1951 onwards, which remained significant regardless of whether positions were treated as a single homogenous group or separated into forwards, defensemen and goalies. However, by increasing the stringency of world's best criteria (i.e., only including players that had achieved hall of fame status), the RAE had dissipated.

The examination of RAEs in super-elite sportsmen appears a fruitful avenue for researchers wishing to better understand the presence and prevalence of RAE at the pinnacle of sport in the modern era. Limitations of previous RAE research include the lack of consideration of inter and intra-sport differences, given how it is conceivable that positional demands likely impact RAE prevalence (Van Rossum, 2006). Furthermore, the criteria used to define the characteristics that constitute levels of expertise have been inconsistent across studies, which can lead to misinterpretations, limiting the identification of important gaps in the field (Coutinho, Fonseca & Mesquita, 2016).

The hypotheses of the current research were two-fold: firstly, to test whether RAEs highlighted thus far extend beyond youth sport and elite sport into the world's 'super elite' performers, whilst controlling for a significant limitation of previous research by considering intra sport differences through assessing RAE prevalence across the different positions. Secondly, to determine whether comparing RAE across different sports at the super-elite level will allow exploration of inter-sport differences. That is, consideration of the unique physical, technical and cognitive demands attached to different sports may assist in identifying *'why'* possible RAEs exist in super-elite performers. Further, we can begin to make inroads in testing the hypotheses that Q1 players' early domination, continues to the super-elite level, indicative of *the survival of the fittest* concept (Christensen et al., 2008). Or, conversely, whether there are mechanisms present in-between these expertise levels that may explain a Q4 overrepresentation. Such mechanisms would be indicative of *the evolution of the fittest* concept (Christensen et al., 2008; Hardy et al., 2017) and may collectively highlight how RAE prevalence is dependent on the nature of a sport and its positional requirements.

Study 1

Method

Participants. The initial sample (n = 262) consisted of male (past and present) cricketers representing players from 9 different International Test teams between 1994 and 2014 (see Supplementary Information for list of teams sampled). International Cricket Council (2014) online player ranking data was adopted as the initial criteria for super-elite status across the different disciplines, on the basis that the players had been recorded in the top 30 in the World in Test format within the 20 year period specified. Cricket disciplines

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were treated as batsmen, spin bowlers, pace bowlers, bowlers combined and all disciplines[1] combined. Subsets of these participants were then identified using 11 criteria of increasing stringency developed from an analysis of the datasets. These criteria were developed with support from ECB national coaches, in recognition of the inconsistent criteria previously used to define level of expertise (for a review see Coutinho et al., 2016) and resulted in *n* decreasing from 262 (least stringent) to 110 (most stringent) (see Table 1). The present criteria served as a means of creating distinctions between levels of super-elite performance, in order to demonstrate the robustness of any potential effects found.

Procedure. The study received institutional ethics approval. The first task was to establish suitable DOB cut-off criteria for each country. This was determined by the competitive calendar for each country and was obtained directly from the international cricket boards. Participant details were cross tabulated according to player's DOB quarters (where Q1= the oldest players and Q4 = youngest players) (see Supplementary Information). Distribution frequencies were categorised according to the cricket disciplines: batsmen, spin bowlers, pace bowlers, bowlers combined and all disciplines combined, in alignment with 11 variations of super-elite status criteria of increasing stringency (see Table 1).

Results

Omnibus Chi-Square Analyses

Given that existing definitions and measurement of super-elite status are somewhat arbitrary, we identified a range of criteria that define super-elite status, and conducted omnibus Chi squared analyses. The analyses involved initial examination of the quarter distributions raw data (see Supplementary Information). Specifically, the frequency of Q1

[1] NB. The wicket-keeping discipline was excluded from the present study due to there being an insufficient sample size represented at the super-elite level to warrant analyses.

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and Q4 overrepresentations were analysed for each discipline across the 11 different criteria. The magnitude of RAEs was also established by computing the effect size (Cohen's *d*). Cohen's *d* represents the ratio between the Chi square value (X^2) and the sample size (*n*) (Cohen, 1988).

Batsmen. Examination of the distribution frequencies for batsmen revealed that Q1 was significantly overrepresented in 9 out of the 11 criteria (X^2 (1, n = 11) = 4.45, p = .03, d = 0.41). Further, Q4 was *not* overrepresented in any of the 11 criteria, and was in fact significantly underrepresented **(**X^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of batsmen in each criterion ranged from 133 (least stringent) to 38 (most stringent).

Spin Bowlers. Examination of the distribution frequencies for spin bowlers revealed that Q1 was significantly overrepresented in 10 out of the 11 criteria (X^2 (1, n = 11) = 7.36, p < .01, d = 0.67), whereas Q4 was significantly underrepresented in all 11 criteria **(**X^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of spin bowlers in each criterion ranged from 40 (least stringent) to 13 (most stringent).

Pace Bowlers. Examination of the distribution frequencies for pace bowlers revealed that Q1 was overrepresented in 7 out of the 11 of the criteria; however, this was *not* significant (X^2 (1, n = 11) = 0.82, p = .37, d = 0.07). Q4 was *not* significantly overrepresented *nor* underrepresented across the criteria (X^2 (1, n = 11) = 0.82, p = .37, d = 0.07).

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Bowlers combined. Examination of the distribution frequencies for bowlers combined revealed that Q1 was significantly overrepresented in all 11 criteria *(*X^2 (1, n = 11) = 11.00, p < .01, d = 1.00), whereas Q4 was significantly underrepresented in all 11 criteria **(**X^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of bowlers in each criterion ranged from 129 (least stringent) to 41 (most stringent).

All disciplines combined. Examination of the distribution frequencies for all disciplines combined revealed that Q1 was significantly overrepresented in all 11 criteria *(*X^2

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(1, n = 11) = 11.00, p < .01, d = 1.00), whereas Q4 was significantly underrepresented in all 11 criteria (X^2 (1, n = 11) = 11.00, p < .01, d = 1.00). The number of cricketers in each criterion ranged from 262 (least stringent) to 92 (most stringent).

Discussion

Results demonstrated a Q1 RAE for all disciplines combined in super-elite cricketers, spanning 9 International Test teams over a 20 year period. These findings showed differential effects when considering the individual disciplines in isolation. A Q1 RAE was evident for batsmen, spin bowlers and bowlers combined, but no RAE was found for pace bowlers in isolation. These differential effects further emphasise the importance of considering the positional requirements of a sport when measuring RAE, given that the requirements can be fundamentally different in nature, impacting RAE prevalence. Our data add new evidence to scant research reporting the traditional RAE at the super-elite level (e.g. Grondin & Trudeau, 1991).

A direct comparisons of RAE prevalence observed in cricket's super-elite with a sport where physicality is fundamental throughout the player pathway will add greater certainty to explanations provided for these findings, by considering inter and intra sport differences. Study 2 will draw comparisons to study 1 by assessing RAE prevalence in super-elite rugby union players, where exceptional physical maturation during early development may be of particular benefit, and remains desirable throughout the pathway. This will assist in indirectly identifying *'why'* differential RAEs exist in super-elite performers, and may begin to highlight how RAE prevalence may be dependent on the nature and positional requirements of a sport.

Study 2

Method

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Participants. The competitive calendar DOB cut-off dates for each country were obtained following correspondence with World Rugby officials. The initial sample of players (n = 690) consisted of male (past and present) international Rugby Union players. Players were selected from the top 10 internationally ranked teams, using the World Rugby official team rankings as of December 31st, 2014 (World Rugby, 2014) (see Supplementary Information for list of countries sampled). Players from these teams were then selected on the basis that they had accumulated a minimum of a single cap between 1994 and 2014. A screening process then took place to determine criteria of incremental stringency for super-elite using player frequency statistics. Subsets of participants were identified for each position using criteria of increasing stringency developed from an analysis of the datasets and resulted in n decreasing from 690 (least stringent) to 87 (most stringent) (see Table 2). Rugby Union positions were categorised as backs, forwards and all positions combined.

Procedure. Given that there are no official rugby union player rankings, the first stage of the study involved developing criteria for super-elite using the player statistics, and specifically the number of international caps. It was then recognised that number of caps alone may not be fully representative of super-elite players, and may instead have included a vast proportion of players with a proven longevity in the 'less successful' teams within the top 10. As such, an additional criterion was implemented which excluded players whose victory rate fell below the combined average of the top 10 teams (50%) alongside the number of caps they held (where sufficient sample sizes allowed this)[2] . The additional stringency meant that the criteria now allowed for players who had played an integral part in the success

[2] Success rate was calculated using the combined average victory rate of each team within the top 10 rankings based on a 20 game period (2012 – 2014). This criterion was not possible for stringency levels 13 and 14 due to an insufficient sample size for further chi-square analysis. This may reflect the super-elite's longevity at international level. That is, number of caps alone may serve as a sufficient metric of super-elite status once players have attained a significant number of caps (i.e., 50+), establishing themselves as international players.

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of teams, over and above that of the average success of the top 10. This resulted in the formulation of criteria consisting of 14 degrees of super-elite (1 = least stringent, 14 = most stringent) (see Table 2), which was then applied to the birth quarters of the competitive calendar for the 10 countries to subsequently assess the prevalence of RAE in the sample.

Results

Omnibus Chi Square Analyses

We identified a range of criteria that define super-elite status, and conducted omnibus Chi squared analyses. The analyses initially involved examination of the quarter distributions raw data (see Supplementary Information). Specifically, the frequency of Q1 and Q4 overrepresentations were analysed for each position across the 14 different criteria.

Backs. Examination of the distribution frequencies for backs revealed that Q1 was significantly overrepresented in 11 out of the 14 of the criteria (X^2 (1, n = 14) = 4.57, p = .03, d = 0.33), whereas Q4 was significantly underrepresented in all 14 criteria **(**X^2 (1, n = 14) = 14.00, p < .01, d = 1.00). The number of backs in each criterion ranged from 304 (least stringent) to 35 (most stringent).

Forwards. Examination of the distribution frequencies for forwards revealed that Q1 was significantly underrepresented in all 14 criteria (X^2 (1, n = 14) = 14.00, p <.01, d = 1.00), whereas Q4 was significantly overrepresented in 11 out of the 14 of the criteria **(**X^2 (1, n = 14) = 4.57, p = .03, d = 0.33). The number of forwards in each criterion ranged from 389 (least stringent) to 52 (most stringent).

All positions combined. Examination of the distribution frequencies for all positions combined revealed that Q1 was significantly underrepresented in 12 out of the 14 criteria (X^2 (1, n = 14) = 7.14, p <.01, d = 0.51). Q4 was overrepresented in 8 out of the 14 criteria, however, this was *not* significant **(**X^2 (1, n = 14) = 0.29, p = .59, d = 1.00). Follow-up Chi-square analysis was required to compare the prevalence of the distribution frequencies of Q1 and Q4, and this analysis revealed that the number of Q4 overrepresentations observed was significantly greater than the number of Q1 overrepresentations observed (X^2 (1, n = 14) = 7.14, p = < .05, d = 0.51). The number of players in each criterion ranged from 691 (least stringent) to 172 (most stringent).

Discussion

Study 2 revealed that backs were subject to the traditional RAE (Q1). For forwards, a reversal of the traditional RAE was evident with those players born later in the year (Q4) being significantly over-represented. Additionally, in the case of all positions combined, Q4 players were also overrepresented. These findings extend previous findings by demonstrating intra-sport differences in RAEs. They also extend the findings of study 1 by assessing RAE inter-sport differences as a means of providing potential explanations for the findings. In this regard, the Q1 RAE observed for backs in rugby union's super-elite provides partial support to the Q1 RAE shown across all of the individual cricket disciplines in study 1.

The investigation of individual positions/disciplines in the current studies has allowed the research to assess RAE prevalence through examining inter-sport differences within cricket and rugby in isolation. The general discussion will examine how the inter-sport differences (and overlap) initially highlighted may be explained by the intra-sport differences evident across cricket and rugby union pathways. This will edge researchers and practitioners alike ever closer to knowing *why* RAEs exist at the super-elite level in sport, and what implications this top-down examination could have for talent identification and development processes.

General Discussion

The present studies sought to examine the presence and prevalence of RAEs in the world's best cricketers and rugby union players over a 20 year period. Extending previous RAE research, a set of stringent criteria for defining super-elite was adopted together with

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categorisation of key positions to explore the previously neglected potential of intra-sport differences in RAE. Findings revealed a Q1 RAE for batsmen, spin bowlers, bowlers combined and when all disciplines were combined, but no RAE was found for pace bowlers. Whilst a Q4 RAE for all the rugby union positions combined, differential RAEs were observed in the case of the individual positons; a Q1 RAE was observed for backs and a Q4 RAE was observed for forwards. These findings provide new evidence of RAEs in super-elite sportsmen.

Previous research has demonstrated that a widespread Q1 RAE exists across junior sports (see Cobley et al., 2009), however this effect has been reported to dissipate at the senior-elite level (Barney, 2015; McCarthy et al., 2016). However, by addressing the methodological problems of treating disciplines and positions as a homogenous group (Van Rossum, 2006), our study offers evidence that sport and positional specific RAEs occur at the super-elite level. We offer two potential explanations for this recurrence of RAEs at the super-elite level by considering how the positional requirements of cricket and rugby union may precipitate the developmental trajectories of super-elite sportsmen.

The back position, where a Q1 RAE is present at the super-elite level, is contingent on a range of tactical elements. Given that the benefits of physical maturation have dissipated, backs need to make use of tactical awareness, formulating strategies and problem solving, to overcome the physical presence of the fully developed opposition forwards; this weighting of cognitive development develops over several years (Myer et al., 2013), consequently, it may not be possible to develop the necessary attributes post-childhood to overcome this mismatch. Sound technique is vital for spin bowlers and batsmen, and the proprioceptive benefits associated with early practice deemed vital in the skill acquisition process, and competition experience aids cognitive development further, and may eventually result in the reliable production of the necessary skills on demand (Masters, 2013). Ultimately, this could mean

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that the best performing Q1 players who have been ever-present in the system, progress to become super-elite players, reflective of the *survival of the fittest* concept.

It appears that the bigger disadvantage for forwards is being advantaged too early. That is, given how early selection bias focusing on physicality alone may disadvantage forwards, as it is based on physical factors that are not sustainable for the future. Specifically, if the bias towards the Q1 players is reflected in junior team selections, these existing Q1 forwards may no longer be in the strongest position by the time physical maturation differences have become less marked. By this point, the Q4 players who have survived within the pathway, or enter later, may possess both the physicality and the mindset to succeed (Coutts, Kempton & Vaeyens, 2014; McCarthy & Collins, 2014 & McCarthy et al., 2016). The success of these Q4 players is attributed to the 'rocky road' development trajectory, where maintaining a desire to train and compete with those of a greater physical stature is likely to develop a degree of psychological resilience and toughness that will prepare players for the challenges faced at the pinnacle of the sport (Collins & McNamara, 2012; Ford & Williams, 2011; MacNamara, Buttons & Collins, 2010). These combative attributes take precedent in the forward position, and the development of these attributes could explain why we see an overrepresentation of Q4 forwards at the super-elite level, indicative of the *evolution of the fittest concept.*

The lack of RAE observed for super-elite pace bowlers suggests alternative explanations. Pace bowling is contingent on both physicality and technique, and given how pace bowlers are required to deliver high speed deliveries which generate bounce; possessing greater height, arm span and strength early on are likely to provide a strong foundation for developing technique. However, poor technique can lead to inconsistent bowling and injuries and thus, the conversion rate of Q1 pace bowlers from junior to senior level may not be linear. It is likely that a proportion of Q4 pace bowlers will have benefited from a non-linear

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development, owing to the likely early bias towards more physically mature Q1 players (Coutts et al., 2014; McCarthy & Collins, 2014; McCarthy et al., 2016). The need to possess physical presence, coupled with robust technique suggests that a proportion of Q4 pace bowlers may remain ever-present along the pathway, or indeed re-enter the pathway. As a result, the relatively younger Q4 pace bowlers who demonstrate robust technique early, with added potential for further growth, are likely viewed as players with high potential, subsequently reducing the disparity in birth quarter conversions from junior to elite level. The present study offers explanations for differential RAEs observed in super-elite sportsmen based on extant literature, and offers further insight through exploring the fundamental differences that exist across sports, and their positions/disciplines. Future research would benefit from a sport-specific, systematic longitudinal study which measures the reported main causes of RAEs (e.g. resilience, maturation) in youth players upon entry into sports programmes (baseline measure). The conversion rates of player progression along the pathway should be tracked and recorded, relative to their birth quarters, simultaneously across a number of significant milestones along the player pathway. Sport administrators may then wish to repeat the baseline measures to ascertain whether any changes have occurred in players' measures, based on experiences during development, which would enable researchers to attach greater certainty to explain *why* disparity in RAE prevalence exists across the expertise continuum. The current message to sport practitioners is that changing early selection criteria by reducing the emphasis placed on physical maturation will reduce RAE bias, and will provide most players with the best opportunities to excel, in effect widening the selection pool. In this regard, the recent application of bio-banding, a method of grouping junior players according to maturational status, as opposed to chronological age (Cumming, Lloyd, Oliver, Eisenmann & Molina, 2017), could well assist with promoting the development and well-being of young athletes by exposing athletes to a broader range of

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challenges and learning contexts. However, RAE is a contributing factor in the efficient turnover of players who do excel, whereby those who do succeed have benefited from the disparity in physical and cognitive maturity within their age cohort. In the case of the Q4 super-elite forwards, they are exceptional, and in the absence of initial RAE bias, they may not have been exceptional. Consequently, we suggest that application of bio-banding should be limited to a confirmatory process, and applied concurrently alongside existing talent development processes, but should not substitute chronological age grouping at present.

Conclusion

In summary, it appears the greater the emphasis placed on physical capability in a given sport, the less likely the Q1 RAE will extend from junior to senior level, due to the ongoing potential of Q4's. This is demonstrated by the Q4 finding observed for super-elite rugby union forwards, indicative of the *evolution of the fittest* concept, where the overcoming of significant challenges associated with the disparity in physical size early on, due to Q1 bias, likely assists in developing resilience and a mindset for achievement at the highest level**.** Further, we conclude that the less weighting placed on physical characteristics, the more likely the Q1 RAE is to persist. This is illustrated by the widespread Q1 RAE observed for cricket batsmen, spin bowlers and rugby union backs. These findings support the *survival of the fittest* concept, where prolonged presence throughout the pathway due to initial Q1 maturity bias supports the development of the cognitive component required for backs, and provides cricketers with a platform to develop the technique required to cope with technical demands at the highest level.

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Table 1. Degrees of criteria for cricket's super-elite criteria and the resultant sample sizes

Stringency	Criteria of Super-elite	n
1 (least)	Ranked top 30 in world; Last 20 years	262
2	Ranked top 30 in world; Last 20 years; Held highest ranking achieved for greater than 1 month	98
3	Ranked top 30 in world; Last 20 years; Played a minimum of 50 international test matches	125
4	Ranked top 30 in world; Last 20 years; Spent minimum of 5 years in the top 30 rankings	92
5	Ranked top 30 in world; Last 10 years; Spent minimum of 1 month in the top 30 rankings	193
6	Ranked top 30 in world; Last 10 years; Spent minimum of 3 years in the top 30 rankings	103
7	Ranked top 20 in world; Last 20 years	204
8	Ranked top 20 in world; Last 10 years; Spent minimum of 1 month in the top 20 rankings	157
9	Ranked top 20 in world; Last 10 years; Spent minimum of 3 years in the top 20 rankings	121
10	Ranked top 10 in world; Last 20 years	147
11 (most)	Ranked top 10 in world; Last 10 years; Spent minimum of 1 month in the top 10 rankings	110

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Table 2. Degrees of criteria for rugby union' super-elite and the resultant sample sizes

Stringency	**Criteria of Super-elite**	**n**
1 (least)	Minimum of 20 caps; Last 20 years	691
2	Minimum of 20 caps; Last 20 years; Minimum of 50% team victory rate	495
3	Minimum of 20 caps; Last 10 years	300
4	Minimum of 20 caps; Last 10 years; Minimum of 50% team victory rate	198
5	Minimum of 30 caps; Last 20 years	489
6	Minimum of 30 caps; Last 20 years; Minimum of 50% team victory rate	354
7	Minimum of 30 caps; Last 10 years	207
8	Minimum of 30 caps; Last 10 years; Minimum of 50% team victory rate	131
9	Minimum of 40 caps; Last 20 years	352
10	Minimum of 40 caps; Last 20 years; Minimum of 50% team victory rate	255
11	Minimum of 40 caps; Last 10 years	135
12	Minimum of 40 caps; Last 10 years; Minimum of 50% team victory rate	87
13	Minimum of 50 caps; Last 20 years	248
14 (most)	Minimum of 60 caps; Last 20 years	172

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SUPPLEMENTARY INFORMATION

International Teams Sampled Within the Study

Study 1 – Cricket:

Australia
Bangladesh
England
India
New Zealand
Pakistan
South Africa
Sri Lanka
West Indies

Study 2 – Rugby Union:

Argentina
Australia
England
France
Republic of Ireland
New Zealand
Samoa
Scotland
South Africa
Wales

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Table. Quarter distribution frequencies of cricketers across super-elite criteria and discipline groups

Criterion of Super- Elite	Disciplines	Q1	Q2	Q3	Q4	χ^2
Top 30 last 20 years	All Disciplines	**79**	64	47	72	7.36
	Batsmen	**37**	33	28	35	1.34
	Bowlers	**42**	31	19	37	9.25*
	Pace Bowlers	28	21	10	**30**	11.00**
n = 262	Spin Bowlers	**14**	10	9	7	2.60
Top 30 last 20 years; held highest rank > 1 month	All Disciplines	**36**	23	17	22	7.20
	Batsmen	**14**	10	10	4	5.35
	Bowlers	**22**	13	7	18	8.41*
	Pace Bowlers	**15**	9	4	14	7.31*
n = 98	Spin Bowlers	**7**	4	3	4	2.01
Top 30 last 20 years; minimum 50 international Test matches	All Disciplines	**44**	25	28	28	4.05
	Batsmen	**25**	20	21	18	0.67
	Bowlers	**19**	5	7	10	11.20*
	Pace Bowlers	**14**	3	3	9	11.68**
n = 125	Spin Bowlers	**5**	2	4	1	3.32
Top 30 last 20 years; spent 5 > years in top 30	All Disciplines	**32**	19	20	21	4.78
	Batsmen	14	12	**15**	8	2.35
	Bowlers	**18**	7	5	13	9.44*
	Pace Bowlers	**12**	4	3	11	8.66*
n = 92	Spin Bowlers	**6**	3	2	2	3.31
Top 30 last 10 years; spent 1 > month in top 30	All Disciplines	**60**	48	36	49	5.57
	Batsmen	**27**	24	20	26	1.18
	Bowlers	**33**	24	16	23	6.09
	Pace Bowlers	**20**	16	10	19	3.74
n = 193	Spin Bowlers	**13**	8	6	4	5.78
Top 30 last 10 years; spent 3 > years in top 30	All Disciplines	**36**	26	24	17	7.17
	Batsmen	**17**	13	15	6	5.39
	Bowlers	**19**	13	9	11	4.31
	Pace Bowlers	**13**	7	5	10	4.20
n = 103	Spin Bowlers	**6**	**6**	4	1	3.94
Top 20 last 20 years	All Disciplines	**58**	54	36	56	6.63
	Batsmen	25	**32**	24	28	1.43
	Bowlers	**33**	22	12	28	10.23*
	Pace Bowlers	22	16	8	**23**	8.28*
n = 204	Spin Bowlers	**11**	6	4	5	4.47

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Top 20 in last 10 years; spent 1 > month in top 20	All Disciplines	**50**	37	30	40	5.26
	Batsmen	**22**	20	19	19	0.30
	Bowlers	**28**	17	11	21	7.89*
	Pace Bowlers	17	12	6	**18**	6.85
n = 157	Spin Bowlers	**11**	5	5	3	6.01
Top 20 in last 10 years; spent 3 > years in top 20	All Disciplines	**41**	29	26	25	5.38
	Batsmen	**17**	13	15	10	3.39
	Bowlers	**24**	16	11	15	5.40
	Pace Bowlers	**17**	11	6	13	5.34
n = 121	Spin Bowlers	**7**	5	5	2	2.68
	All Disciplines	**50**	32	32	33	4.86
Top 10 in last 20 years	Batsmen	**23**	20	21	11	4.16
	Bowlers	**27**	12	11	22	10.11*
	Pace Bowlers	**19**	7	7	18	10.40*
n = 147	Spin Bowlers	**8**	5	4	4	2.05
Top 10 in last 10 years; spent 1> month in top 10	All Disciplines	**39**	27	19	25	6.22
	Batsmen	**17**	15	13	8	4.56
	Bowlers	**22**	12	6	17	9.45*
	Pace Bowlers	13	9	3	**14**	9.83*
n = 110	Spin Bowlers	**9**	4	3	3	5.64

Note: **Bold** numbers indicates overrepresentation among birth quarters

* < .05   ** <.01

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Table. Quarter distribution frequencies of rugby union players across super-elite criteria and positions aligned with individual competitive season cut-offs

Criterion of Super- Elite	Positions	Q1	Q2	Q3	Q4	χ^2
Minimum 20 caps; Last 20 years *n* = 691	All Positions Backs Forwards	152 75 77	**184** **78** 106	173 75 98	182 74 **108**	3.72 0.11 6.21
Minimum 20 caps; Last 20 years; 50% > Team Success *n* = 495	All Positions Backs Forwards	108 **55** 53	122 54 68	123 51 72	**142** 51 **91**	4.71 0.25 10.33*
Minimum 20 caps; Last 10 years; *n* = 300	All Positions Backs Forwards	72 **39** 33	68 30 38	75 31 44	**85** 34 **51**	4.50 1.47 4.51
Minimum 20 caps; Last 10 years; 50% > Team Success *n* = 198	All Positions Backs Forwards	47 **24** 23	47 20 27	49 17 32	**55** 22 **33**	0.88 1.30 2.26
Minimum 30 caps; Last 20 years; *n* = 489	All Positions Backs Forwards	115 **59** 56	**134** 58 76	112 51 61	128 47 **81**	2.69 1.84 6.20
Minimum 30 caps; Last 20 years; 50% > Team Success *n* = 354	All Positions Backs Forwards	78 38 40	**93** 38 55	90 **41** 49	**93** 34 **59**	1.74 0.65 4.04
Minimum 30 caps; Last 10 years *n* = 207	All Positions Backs Forwards	57 **28** 19	49 21 28	43 15 28	**58** 22 **36**	2.43 3.96 5.21

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Minimum 30 caps; Last 10 years; 50% > Team Success *n* = 131	All Positions Backs Forwards	**36** **20** 16	32 12 20	29 9 20	35 14 **21**	0.63 4.70 1.15
Minimum 40 caps; Last 20 years *n* = 352	All Positions Backs Forwards	**96** **41** 55	92 33 **59**	83 33 50	81 27 54	1.76 3.95 0.74
Minimum 40 caps; Last 20 years; 50% > Team Success *n* = 255	All Positions Backs Forwards	60 **28** 32	63 26 37	60 21 39	**72** 24 **48**	3.52 1.08 3.44
Minimum 40 caps; Last 10 years *n* = 135	All Positions Backs Forwards	35 **20** 15	34 19 15	27 7 20	**39** 14 **25**	2.22 7.08 3.66
Minimum 40 caps; Last 10 years; 50% > Team Success *n* = 87	All Positions Backs Forwards	24 **13** 11	18 6 12	19 5 14	**26** 11 **15**	2.06 5.11 0.78
Minimum 50 caps; Last 20 years *n* = 248	All Positions Backs Forwards	56 **31** 25	56 21 35	**71** 22 **49**	65 25 40	2.62 2.46 8.08*
Minimum 60 caps; Last 20 years *n* = 172	All Positions Backs Forwards	27 16 11	47 16 31	**65** **25** **40**	33 12 21	19.91** 5.26 18.24**

Notes: **Bold** numbers indicates overrepresentation among birth quarters

***** < .05 ****** <.01